

PAPER • OPEN ACCESS

Implementation of a Policier-Based Control Loop For The Dynamic Resource Allocation of a Software-Defined Communication Infrastructure

To cite this article: A S Klimova *et al* 2020 *J. Phys.: Conf. Ser.* **1694** 012006

View the [article online](#) for updates and enhancements.



The Electrochemical Society
Advancing solid state & electrochemical science & technology
2021 Virtual Education

Fundamentals of Electrochemistry:
Basic Theory and Kinetic Methods
Instructed by: **Dr. James Noël**
Sun, Sept 19 & Mon, Sept 20 at 12h–15h ET

Register early and save!



Implementation of a Policier-Based Control Loop For The Dynamic Resource Allocation of a Software-Defined Communication Infrastructure

A S Klimova, S D Kodolov, A Yu Filimonov and O P Aksyonova

Ural Federal University, Ekaterinburg, Russia

E-mail: alina_klimova1503@mail.ru, sergey.kodolov@urfu.ru, a.filimonov@urfu.ru, wiper99@mail.ru

Abstract. The use of solutions based on the principles of virtualization is designed to increase the efficiency of using the communication infrastructure due to the dynamic distribution of existing communication and computing resources between their virtual components. The software management of the communication infrastructure components opens up opportunities for applying new approaches to solving the currently very urgent problem of ensuring the required Quality of Service. Taking into account the current trends in the development of communication infrastructures and means of their automation, it seems relevant to build systems that implement a closed cycle of communication infrastructure resource management based on traditional and promising tools for monitoring and managing QoS and studying its behavior. Closing the control loop is achieved by implementing a control script that automatically responds to changes in the transmitted data and makes decisions about changing the current configuration of network devices. One of the approaches to building a closed control loop is to change the physical bandwidth of a virtual communication channel depending on the intensity of its resource use. The paper considers an example of the implementation of a closed control loop based on the rules of the policy for limiting the rate of sending packets of heterogeneous traffic and compares the approach of dynamic bandwidth redistribution with traditional approaches.

1. Introduction

The intensive penetration of Internet technologies into all spheres of modern society leads to an exponential increase in the load on the existing communication infrastructure [1]. The use of solutions based on the principles of virtualization of network functions and resources was intended to increase the efficiency of using the network infrastructure due to the dynamic allocation of resources between its virtual components [2]. The basic principle of virtualization is the division of a physical resource between independent virtual objects. In telecommunications systems, this principle is applied to form virtual overlay networks [3] to create virtual network slices [4] on top of the real (underlay) network infrastructure. According to the Network Functions Virtualization (NFV) classification of the ETSI Industry Specification Group (ISG), this approach is called Virtual Partitioning [5]. Using this approach, the resources of the real carrier network (underlay network) are allocated between virtual components and virtual channels of overlay networks. The increase in the volume of data transmitted through communication infrastructures causes an increase in the requirements for the communication resources of the underlay networks, which have physical limitations which are already tangible in wireless and cellular networks now [6].



Therefore, for critical applications, packet rate-based solutions are used that provide different levels of guaranteed quality of service (QoS) for different layers of overlay networks. It should be noted, however, that these solutions restrict the output rate to a maximum value. Therefore, for critical applications, packet rate-based solutions are used that provide different levels of guaranteed quality of service (QoS) for different layers of overlay networks. It should be noted, however, that the only ability of these solutions is to restrict the output rate to a maximum value. Importantly, neither mechanism provides a minimum bandwidth guarantee during periods of congestion [7]. In addition, when transmitting “explosive” streaming traffic (for example, video traffic), an incorrect setting of the limitation level can either lead to inefficient use of the channel bandwidth, or to a significant decrease in image quality [8]. In these conditions, it is of interest to consider the possibility of dynamic control of traffic limiting parameters which can significantly increase the efficiency of using the channel bandwidth while ensuring a given QoS level. In modern communication infrastructures, such control can be implemented within the framework of the concept of software-defined networks (PCN, Software-Defined Network, SDN) which became the starting point for the implementation of integrated automation in communication infrastructure management systems [9]. As one of the possible approaches to using SDN tools to solve the task at hand, we can consider the construction of a software controller that implements a closed loop of monitoring and control to increase the efficiency of using the resources of the underlay infrastructure. In practice, this approach can be implemented, for example, for traffic management of a distributed laboratory complex that includes training classes in which laboratory classes are conducted on the study of VoIP, WLAN, and the basics of building software-defined network infrastructures. Both virtual and hardware components of the network infrastructure are used as part of the classes which makes it possible to increase the efficiency of using the existing equipment, intensify the learning process and at the same time avoid the use of non-essential material components [10]. Since in such a complex the traffic of various applications is transmitted, it is quite easy to build a program-controlled multilayer communication infrastructure. The programmability of the components of this infrastructure will provide the ability to dynamically reallocate underlay network resources between virtual overlays in real time in accordance with current application requirements. The presence of hardware components in such a complex will visually assess the effectiveness of software management of the components of this infrastructure. In this paper, we consider the construction of a software controller for the implementation of a closed-loop control of the dynamic resource allocation of data transmission channels of a distributed laboratory complex.

2. Quality of Service Tools and Methods

Quality of Service (QoS) is an approach to managing limited resources in order to provide the required quality of service. Quality of service metrics for network infrastructures are traffic losses and delays. Quality of Service is one of the most important network requirements. The existing number of types of heterogeneous traffic in the event of queues during data transmission necessitates its prioritization. The most popular and widespread model of this approach is “Differentiated Services” [11]. The model is based on the concept of Per-Hub Behavior, when each node processes the traffic passing through it and decides on its importance independently. The tools used in this model are: Policer, Dropper, Scheduler, Shaper. Different classes of service can be provided depending on the parameters of these instruments (Class of Service). CoS mechanisms are discussed in the order in which they apply to traffic entering the device. Classification. Before operating with traffic, it is classified. The classification is made based on the labeling in the packet header (Behavior Aggregate), based on the interface to which the traffic comes (Interface-based), and on the basis of other fields in the packet header (MultiField). During classification, the package is associated with one of the behavior models (Default Forwarding, Best Effort, Assured Forwarding, Expedited Forwarding, Class Selector, etc.) [12]. Queuing.

After classification, the packet is placed in the queue corresponding to its priority. A packet can leave the queue if it reaches the head of the queue, and if the queue is full and the packet is discarded, and the packet is also discarded if it lingers in the head of the queue for too long. Such mechanisms are called Tail- and Head-Drop. Shaping и Policing. These mechanisms ensure that the interface is not overloaded in accordance with its bandwidth. Policer drops all packets of traffic that exceeds the bandwidth of the interface. Shaper delays packets in the queue, distributing the traffic burst over time. Scheduling. [13] The scheduler fetches packages from the queue. There are various mechanisms for removing packets from the queue. Among them there are First In First Out (FIFO), Priority Queuing (PQ), Fair Queuing (FQ), Deficit Weighted Round Robin (DWRR), Class-Based Weighted Fair Queuing (CBWFQ). The most common today are the latter: DWRR, and CBWFQ and their derivatives [11]. DWRR follows this algorithm: for all queues, the maximum number of bits that can be transmitted in one cycle is determined. After retrieving packets from all queues, each queue adds the previously defined number of bits to the remainder. The cycle is repeated. CBWFQ divides traffic into eight (or fewer) classes and therefore eight queues. Each class has its own dequeue priority. The advantage of this approach is that several types of traffic are combined into one class. When choosing CoS mechanisms, it should be borne in mind that for streaming traffic, packet delay is a critical indicator in ensuring quality of service as opposed to the rate of packet loss. Based on the above description, for streaming traffic where packet latency is more critical, choosing between Shaping and Policing, it is advisable to opt for policing since when using a shaper, packets are delayed which will not provide quality of service. When polishing is used, lost packets are dropped to ensure the quality of the image transmission.

3. Distributed Laboratory Complex Implementation

Taking into account the current trends in the development of communication infrastructures and means of their automation, it seems relevant to study systems that implement a closed cycle of communication infrastructure resource management based on traditional and promising tools for monitoring and managing QoS. Let's consider an example of building a model of such an SDN infrastructure based on CLA principles using the Policer tool, and compare the results of studying its dynamic characteristics with the characteristics obtained when operating without dynamic allocation of virtual resources of a fixed communication channel. The experimental stand was prepared on the basis of the laboratory complex for conducting classes on the study of technologies such as routing, VoIP and software-defined network infrastructures [14]. This laboratory complex uses communication infrastructure management platforms [15] and hardware components from leading manufacturers of communication equipment. The connection diagram of the VoIP stand is shown in Fig. 1 for two subscribers from different networks.

The laboratory complex used R-Edge1, R-Edge2 and Router routers, SW and SW PoE switches, IPTel-1,2 telephones as well as SrvPBX and iperf servers. A complete list of equipment is shown in Table 1 for the experimental bench. The SrvPBX resource is used to create IPBX virtual PBXs, the iperf server resource is used to generate low-priority traffic between the border routers, the resources of the R-Edge1 and R-Edge2 border routers are used to route traffic between subscribers of neighboring subnets as well as for marking and filtering traffic, the PoE switch provides connection of phones to the virtual infrastructure, the SW switch is used to manage the components of the virtual infrastructure of the complex during laboratory work, the Router, if necessary, provides the components of the network infrastructure with access to the Internet.

Heterogeneous traffic is generated by the virtual endpoints of the local subnets (IP-Tel1,2; iperf1,2). In the considered topology, the traffic arising from a video call between IP-Tel1,2 subscribers of virtual PBX acts as a high-priority traffic. Low-priority traffic is generated by iperf1,2 virtual machines using the iperf utility. This traffic is a stream of both UDP and TCP

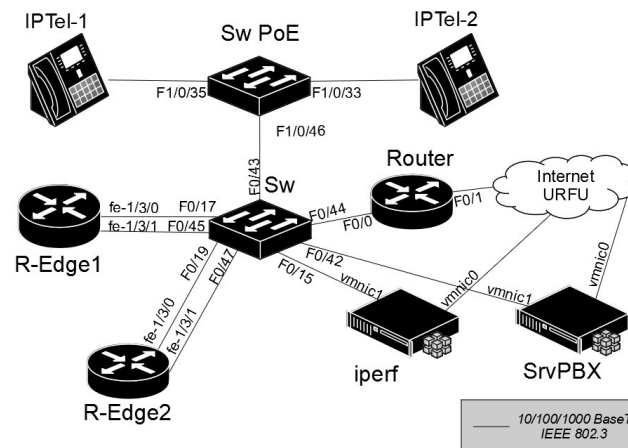


Figure 1. Hardware infrastructure of the VoIP stand.

Table 1. Equipment

Label	Hardware	Software
R-Edge1,2	Routers Juniper M7i	JUNOS 11.1R4.4
Router	Router Cisco 2801	Cisco IOS Software, Version 15.1 (2) T1
Sw PoE	Switch Cisco WS-C3750-48P	Cisco IOS Software, Version 12.2 (55) SE11
Sw	Switch Cisco WS-C2960-48TT-L	Cisco IOS Software, Version 15.0 (2) SE4
SrvPBX	Server HP ProLiant DL380 G5	VMware ESXi 5.5.0
iperf	Server HP ProLiant DL160 G6	VMware ESXi 5.5.0
iperf1,2	Virtual machines	Utility iperf 2.0.12
vPBX1,2	Virtual PBXs	Asterisk 16.3.0
IPTel-1,2	Cisco Unified IP Phone 9971	9971 SIP IP Phone CUCM Versions: 9.4(2)SR4 [9]

packets from client to server between adjacent subnets. Edge routers are the endpoints of an organization's network infrastructure. Therefore, the carrier infrastructure for traffic between R-Edge1 and R-Edge2 is the organization's infrastructure. In the case of a laboratory complex, this infrastructure is a router (Router). The logical topology of the laboratory bench is shown in Fig. 2. Virtual components are shown in gray, physical components are shown in black.

The use of telephone equipment is due to the fact that the traffic transmitted between subscribers is related to voice traffic and multimedia streams which should have the highest priority over the rest of the traffic. QoS technology is implemented in the form of Class-of-

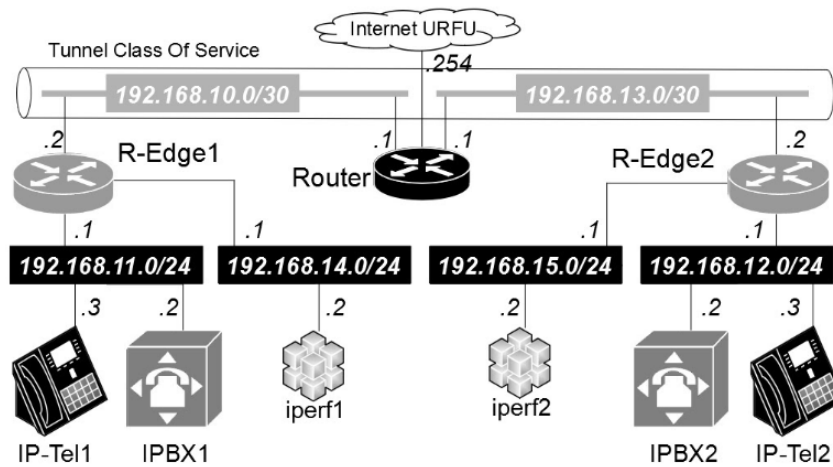


Figure 2. Logical topology.

Service (CoS) settings on the Juniper hardware used to build the laboratory complex. Using CoS settings allows you to classify heterogeneous traffic, defining broadcast priority for each class. To differentiate the types of traffic in the experimental stand, it was decided to distinguish VoIP and Service as two independent classes. The VoIP class includes voice and multimedia traffic for which the highest priority is set, all other traffic belongs to the Service class. Traffic classification is carried out using firewall filters. Classified traffic is processed according to specific requirements. This method is called filter based routing. In order to improve the quality of experiments, due to the known interface with high priority traffic, it was decided to classify traffic based on the source interface. In accordance with a certain class, an incoming packet is assigned to one of two queues.

4. Experiment Layout and Measurement Results

To implement a closed traffic control loop, a script was carried out that manages queues, automatically responds to changes in the transmitted data and makes decisions about changing the current configuration of network devices, reallocating fixed bandwidth resources between high-priority and low-priority traffic. Such a script can be located both independently of the controlled equipment, providing orchestration, or directly on the network equipment. In the second case, device configuration management is performed by the device itself. A promising area of research is the introduction of machine learning elements into the process of building network infrastructures. In this case, the system not only changes the configuration of devices based on preset parameters but also becomes able to calculate such parameters on its own. The first test version of the program is implemented as an external control script in the Python programming language. Source code is provided at Rtf hardware and software stand repository [16]. In the course of previous studies [14], it was found that for transferring a static image, a bandwidth of at least 110 Kbps is required, and for transferring a dynamic image, at least 170 Kbps is required. Based on this, the controller's operation algorithm is as follows: the current baud rate of the voice traffic source interface is measured; if there is no voice traffic, then the entire transmission bandwidth is allocated for service traffic (200 Kbps); if the voice traffic rate exceeds the lower threshold, the service traffic rate is reduced to 70Kbps, guaranteeing the bandwidth for the static image. If the voice traffic rate exceeds the upper threshold value of the static image, then 20Kbps is allocated for service traffic and the rest of the bandwidth is allocated for the transmission of

priority traffic; the cycle repeats. The block diagram of the algorithm is shown in Fig. 3.

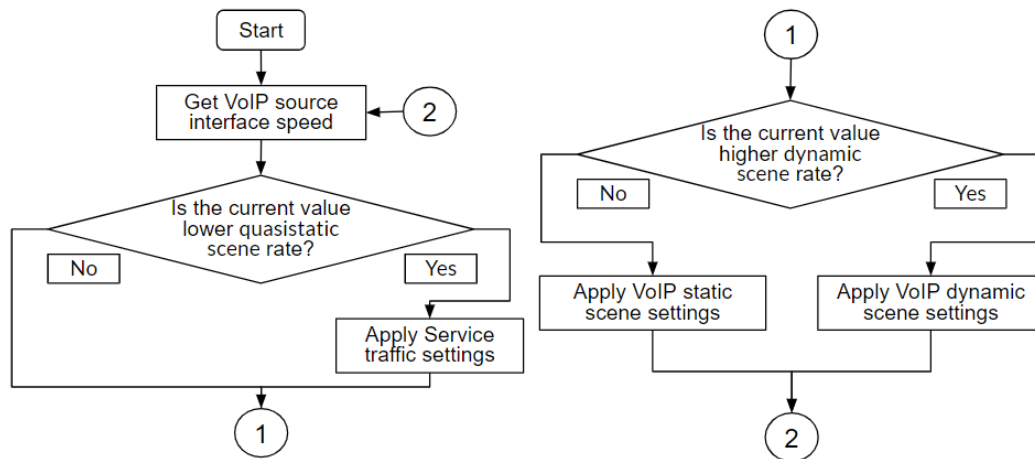


Figure 3. Block diagram of the control script functioning algorithm.

During the experiments, using the iperf utility, we simulated a file transfer from one workstation to another. In parallel with the file transfer, a video call was made, affecting the transfer rate. Four experiments were carried out. In the first experiment, the maximum file transfer rate was measured in the absence of a video call. In the second case, the file transfer rate was measured with a bandwidth guaranteeing a video call with a static picture. In the third case, similarly to the second, the file transfer rate was measured with a bandwidth guaranteeing free passage of a video call with both a static image and a dynamic one. In the last experiment, the file transfer rate was measured under the conditions of dynamically changing the bandwidth using the controller depending on the intensity of the video call bandwidth. The average experimental results are presented in Table 2.

Table 2. Transfer rate versus bandwidth

Experiment	All band service traffic	70 Kbps band service traffic	20 Kbps band service traffic	Dynamic bandwidth allocation
1	179.177	61.207	25.874	43.471
2	182.797	60.958	28.345	61.747
3	180.593	60.632	29.631	43.771
4	181.347	61.043	26.124	40.509
Average, Kbps	180.979	60.960	27.494	47.374

You can see that the maximum file transfer rate in the absence of a video call is 180 Kbps. With this mode of bandwidth use, the quality of video communication will be insufficient to obtain a detailed image and Quality of Service will not be provided. With a severe limitation of the bandwidth of the communication channel for file transfer up to 70 Kbps, the average transfer rate is approximately 60 Kbps. In this case, VoIP traffic is transmitted at a speed sufficient only for a static image and voice. Full video communication is not possible. By limiting the channel bandwidth for file transfer to 20 Kbps, the controller provides a high QoS level for VoIP, but

low for service traffic, and the average file transfer rate is 27 Kbps. With dynamic bandwidth allocation in four experiments, the average file transfer rate is approximately 47 Kbps. This is almost twice as high as with a severe limitation of the channel bandwidth for service traffic. At the same time, the controller adapted to the intensity of VoIP bandwidth usage and ensured high QoS for all types of traffic. The obtained results show that the maximum efficiency of use is achieved with dynamic bandwidth control of the communication channel and the redistribution of resources between different types of traffic.

5. Conclusion

Modern communication infrastructures are experiencing an increase in the load due to permanent growth in the number of Internet applications and their growing activity. As modern applications place ever higher demands on the resources of communication infrastructures, the task of increasing the efficiency of using these resources becomes more and more urgent. The application of the principles and protocols of program-based control for the components of the communication infrastructure makes it possible to solve this problem by building a controller program designed to monitor the parameters of limiting the transmitted traffic. In this work, the implementation of the controller program and its use as part of a closed-loop control of the dynamic allocation of resources of data transmission channels of a distributed laboratory complex were considered. The infrastructure of this complex includes classrooms in which laboratory classes are held on the study of VoIP, WLAN. The programmability of the communication infrastructure components of this complex provided the possibility of dynamic reallocation of the carrier network resources between virtual layers in accordance with the requirements of active applications. The presence of both virtual and hardware components in the complex made it possible to determine and visually evaluate the effectiveness of software management of the components of this infrastructure. The carried out tests confirmed an almost twofold increase in the efficiency of using the resources of the communication infrastructure of the laboratory complex when using an external controller program. As possible directions for further research and development, the launch of a controller program under the OS control of the communication infrastructure components (on-box controller) and comparative studies of the dynamic characteristics of external and on-box controllers can be considered.

Acknowledgments

This work is supported by Act 211 Government of the Russian Federation, contract #02.A03.21.0006

References

- [1] Cisco annual internet report - cisco annual internet report (2018–2023) white paper URL <https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html>
- [2] Wang A, Iyer M, Dutta R, Rouskas G N and Baldine I Network virtualization: Technologies, perspectives, and frontiers vol 31 pp 523–537 ISSN 0733-8724 URL <http://adsabs.harvard.edu/abs/2013JLwT...31..523W>
- [3] Galan Jimenez J and Gazo Cervero A Overview and challenges of overlay networks: A survey vol 2 pp 19–37 ISSN 09763252 URL <http://www.airccse.org/journal/ijcses/papers/0211cses02.pdf>
- [4] Gutz S, Story A, Schlesinger C and Foster N 2012 Splendid isolation: A slice abstraction for software-defined networks *Proceedings of the First Workshop on Hot Topics in Software Defined Networks HotSDN '12* (New York, NY, USA: Association for Computing Machinery) p 79–84 ISBN 9781450314770 URL <https://doi.org/10.1145/2342441.2342458>
- [5] ETSI GS NFV-INF 005 v1.1.1 (2014-12) - network functions virtualisation (NFV); infrastructure; network domain URL https://www.etsi.org/deliver/etsi_gs/NFV-INF/001_099/005/01.01.01_60/gs_NFV-INF005v010101p.pdf
- [6] Salman M, El-Keyi A, Nafie M and Hasna M 2015 Novel cooperative policy for cognitive radio networks: Stability region and delay analysis

- [7] Comparing traffic policing and traffic shaping for bandwidth limiting URL <https://www.cisco.com/c/en/us/support/docs/quality-of-service-qos/qos-policing/19645-policevsshape.pdf>
- [8] Filimonov A, Aksyonov A, Klimova A and Kodolov S Building a laboratory bench for the study of software-configurable network infrastructures vol 63 pp 178–186 ISSN 00213454 URL http://pribor.ifmo.ru/en/article/19458/postroenie_laboratornogo_stenda_dlya_issledovaniya_programmno_konfiguriruemyh_setevyh_infrastruktur_.htm
- [9] Software-defined networking: The new norm for networks URL https://www.techylib.com/en/view/shapcart/software-defined_networking_the_new_norm_for_networks
- [10] Filimonov A, Medvedev D, Klimova A and Muravyov A Application of virtual infrastructure components in construction of a laboratory complex in an educational institution vol 61 pp 1092–1099 ISSN 00213454 URL http://pribor.ifmo.ru/en/article/18361/primenenie_komponentov_virtualnoy_infrastruktury_pri_postroenii_laboratornogo_kompleksa_v_uchebnom_zavedenii_.htm
- [11] Networks for the hardest. fifteenth part. QoS URL <https://habr.com/ru/post/420525/>
- [12] Chan K H, Babiarz J and Baker F Configuration guidelines for DiffServ service classes URL <https://tools.ietf.org/html/rfc4594>
- [13] Junos OS class of service configuration guide URL <https://www.juniper.net/documentation/software/junos-security/junos-security10.4/junos-security-swconfig-class-of-service/index.html>
- [14] Klimova A, Kodolov S, Aksyonov K and Filimonov A 2019 Implementing dynamic management of virtual network infrastructure components vol 2525 (CEUR-WS) ISSN 1613-0073
- [15] Chef vs puppet vs ansible vs saltstack: Which one to choose section: DevOps URL <https://www.edureka.co/blog/chef-vs-puppet-vs-ansible-vs-saltstack/>
- [16] KlimovaAlina RTF hardware and software stand repository URL <https://github.com/KlimovaAlina/SDN>